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COMPARATIVE EVALUATION OF EXPOSURE DISTRIBUTIONS FOR AIR TRAVELERS AND RADIATION WORKERS

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Radiation workers contribute 0.48 millirem/year per capita of the total U.S. population. Air travelers exposed to increased environmental radiation levels at altitude contribute 0.54 millirem/year. However, the two respective distributions differ greatly in all other parameters; namely, number of individuals involved, magnitude and spread of individual exposure, and skewness. While the distribution for radiation workers centers heavily on near-zero exposures and reaches out to large excursions in rare cases of accidents, the one for air travelers shows a narrow spread, excludes excursions completely, and does not constitute an additional radiation risk.

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SUMMARY PAGE

THE PROBLEM

If the population dose from public air travel due to the increased galactic radiation level at altitude is computed and compared to the corresponding dose contributed by radiation workers, it is found that the two are very nearly equal. However, behind this apparent equality, profoundly different distributions of individual exposures for the two populations remain hidden. A realistic appraisal of the public-health implications of the two man-made additions to the natural background of ionizing radiation requires a comparison of the distributions rather than the total doses.

FINDINGS

Although existing information on the galactic dose equivalent in the 30,000- to 40,000-foot altitude region as well as on the traveling habits of individual air passengers is not so accurate nor so complete as the data on exposures of radiation workers issued by the Atomic Energy Commission, a reasonably reliable model for the distribution of passenger miles and hours at altitude among the United States population can be established. Evaluation of the data leads to mean yearly doses of 3.8 millirems for airline passengers and 245 millirems for radiation workers, whereas the corresponding total radiation loads are 99,878 and 112,473 man-rems, respectively. Population doses are 0.54 millirem/year per capita from air travel and 0.48 millirem/year from radiation workers.

The differences in distributions of the two population doses are only partially explained by the obvious fact that their near-equality is due to the compensation of the much smaller number of radiation workers by correspondingly larger individual exposures. It is found that the exposure distribution for radiation workers is more heavily skewed toward zero exposure, yet extends, for very few individuals, to very high exposures, reflecting rare instances of emergencies and accidents. In contrast, the distribution for air travelers shows a narrow spread, excluding large excursions of exposure completely since even for a continuous stay at altitude the exposure would still remain below the maximum permissible dose for radiation workers.

In an earlier publication (1) existing information on the galactic radiation level throughout the atmosphere was reviewed, with special emphasis on establishing data on the radiation exposure of passengers at conventional jet and supersonic transport altitudes. By combining these data with those on the total passenger miles per year as reported by airlines the contribution of commercial air travel to the population dose was evaluated and compared with other man-made additions to the dose from the natural background of ionizing radiation. It was found that the population dose from air travel very nearly equaled the corresponding dose contributed by radiation workers under the control of the Atomic Energy Commission (AEC). The earlier study briefly mentioned the obvious fact that the two contributions accrue from population groups of vastly different sizes but did not investigate this particular aspect in more detail. A realistic assessment of the public-health implications requires a comparative evaluation of the respective distributions of individual exposures among the two populations involved (airline passengers and radiation workers). The present study is a first step toward this goal.

Unfortunately, available information on the travel habits of the individual airline passenger is incomplete with regard to some parameters of importance for the present investigation. Limitations also exist in regard to the galactic radiation level in the 30,000- to 40,000-foot altitude region. While the so-called total ionization has been well investigated, uncertainties still exist concerning the contributions of disintegration stars in tissue and of galactic neutrons to the total dose equivalent. Because of these shortcomings the dose distribution for airline passengers cannot be established with the same accuracy as for radiation workers. Nevertheless, the basic differences of the two distributions can be clearly demonstrated with the data at hand.

A review of the galactic radiation level throughout the atmosphere was given in the earlier study (1). It has to be supplemented, in the present context, with data from air-travel statistics. All United States passenger airlines issue monthly reports on revenue passenger miles (RPM) flown on domestic and international routes. This information, however, does not convey clues as to the number of trips by individual passengers. Limited data on this aspect of air travel can be extracted from a study for the Air Transport Association of America (ATAA) (2). That study presented the results of a poll that sampled the adult population of the United States and that included three questions apart from those pertaining to general demographic information. The three questions relevant to air travel were: 1) Had the respondent ever flown? 2) Had he flown in the past 12 months? 3) If he had flown in the past 12 months, how many trips did he make? The survey was conducted in June 1970. According to the Bureau of Census, the adult United States population (21 years of age and older) in 1970 amounted to 119,200,000 persons (excluding the institutional population). By projecting the results of the poll to the total adult population in 1970, it follows that 47 per cent, or 56,024,000, had ever flown whereas 22 per cent, or 26,224,000, had flown in the past 12 months. The distribution of the numbers of trips among the 22 per cent is shown in Table I. Column 2 is taken directly from the original study. It is seen that trip numbers are lumped in groups of two and six and that the number of passengers drops steeply as the number of trips increases. For the latter reason it would seem preferable to establish a smooth distribution of best fit, with trip numbers increasing in steps of one.

Table I

Distribution of Trip Numbers Among 22 Per Cent of Adult United States Population Who Flew on a Regular Passenger Airline From June 1969 to June 1970

Number of Trips	Per Cent of Population	
	ATAA Data*	Modified Distribution#
1 or 2	12	12
3 or 4	4	4
5 or 6	2	2
7 to 12	2	2.93
13 to 18	1	0.866
19 or more	1	0.204

* From reference 2.
\# See Table II for complete distribution.

Table II

Distribution of Trip Numbers and Exposures
for Adult United States Air Travelers

Trips/Year or Millirems/Year	Per Cent Adult Population	Individual Passengers, (000,000)	Individual Passengers, (per cent)	Passenger Trips/Year or Man-Millirems/Year (000,000)
1	8.0	9.536	36.4	9.536
2	4.0	4.768	18.2	9.536
3	2.4	2.861	10.9	8.583
4	1.6	1.907	7.27	7.628
5	1.1	1.311	5.00	6.555
6	0.9	1.073	4.09	6.438
7	0.76	0.906	3.45	6.342
8	0.62	0.736	2.81	5.888
9	0.52	0.620	2.36	5.580
10	0.42	0.501	1.91	5.010
11	0.34	0.405	1.54	4.455
12	0.27	0.322	1.23	3.864
13	0.22	0.262	1.00	3.406
14	0.18	0.215	0.820	3.010
15	0.15	0.179	0.683	2.685
16	0.125	0.149	0.568	2.384
17	0.105	0.125	0.477	2.125
18	0.086	0.103	0.393	1.854
19	0.070	0.083	0.317	1.577
20	0.047	0.056	0.214	1.120
21	0.036	0.043	0.164	0.903
22	0.022	0.026	0.099	0.572
23	0.014	0.017	0.065	0.391
24	0.010	0.0119	0.045	0.286
25	0.005	0.0061	0.023	0.150
26	0	0	0	0
Total	22	26.216	100	99.878

Table II shows such a distribution established from the data in Table I by trial and error, keeping the original subgroup entries intact as far as possible. While the latter condition offers no difficulties for the entries in the first three lines of Table I, there exists no set of continuously declining values for the number of passengers which would also leave the last three lines intact. Presumably, this discrepancy is due to rounding off percentages to integer numbers in the original set. The third column in Table I lists the group entries as they follow from the modified distribution shown in Table II.

If the data in Table II are to be evaluated in terms of radiation exposure, the mean time at altitude per trip has to be determined. Available information on this quantity is incomplete, in the ATAA study as well as in all other documents of the Federal Aviation Administration (FAA) and the Civil Aeronautics Board (CAB). For domestic air travel the mean and median lengths per trip are well established; for 1969 they equaled 848 and 580 miles, respectively. Since an unknown fraction of the passengers polled in Table I traveled on international routes, the value of 848 miles per trip must be considered the lower limit of the interval containing the unknown correct value. An upper limit can be established from the total RPM flown by all United States carriers from June 1969 to June 1970. That value is 145,700,000,000 RPM (3). Since a certain fraction of this mileage has been flown by foreign nationals not contained in the population sampled in Table II, the value for the mean length of one trip is too high if we would apply the quoted RPM value uncorrected. Actually doing so, we obtain a mean length per trip of 1458 miles. We know, then, that the true value must lie between 848 and 1458 miles. By trial and error we find that a mean duration of 2.5 hours per trip and a mean ground speed of 500 miles per hour lead to a mean length per trip of 1250 miles, closely matching the mean value of 1153 miles from the just-quoted upper and lower limits.

Another parameter to be defined is mean flight altitude. According to the CAB (S. J. Gerathewohl, personal communication), three different mean flight altitudes are usually distinguished: 39,000 feet for Pacific flights, 35,000 feet on north Atlantic routes, and 31,000 feet for domestic flights within the continental United States. The quoted values represent mean cruising altitudes, excluding climb and descent. Since the mean flight altitude defines the mean galactic radiation level during flight, the connection of the two magnitudes has to be closely investigated. In the earlier study (1) the existing information on the galactic dose equivalent throughout the atmosphere in its dependence on altitude, latitude, and the solar cycle has been reviewed. In the meantime, newer data (4) have become available from a study sponsored by the FAA expressly for a more reliable assessment of passenger exposures on commercial flights. Measurements, conducted by F. P. Cowan with a dose equivalent rate meter developed at Brookhaven National Laboratory, sampled the galactic radiation level from 30,000- to 60,000-foot altitude with a B-57F jet aircraft. The resulting altitude profile is shown in Figure 1. Inasmuch as the measurements were conducted with an airplane rather than with a balloon, using an instrument developed and extensively tested for low-level

radiation monitoring of neutron radiation fields, they must be considered the most pertinent and reliable information in the present context.

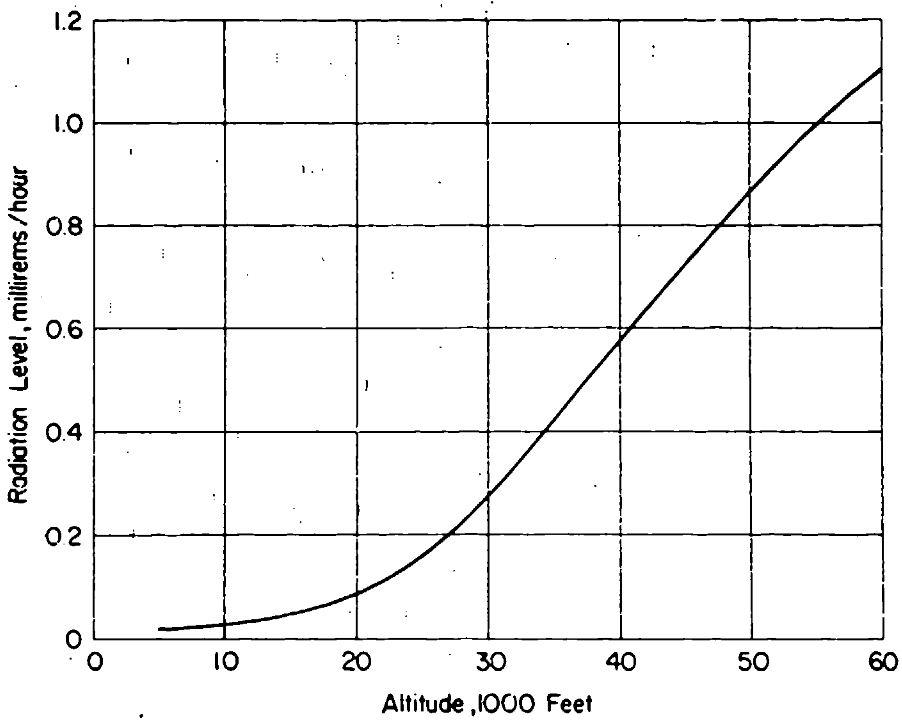

Figure 1

Altitude Profile of Galactic Radiation Level at Northern Latitudes (From Reference 4.)

It is seen from Figure 1 that the galactic dose equivalent rises steeply within the range of the three representative mean flight altitudes quoted above, increasing from 0.3 millirem/hour at 31,000 feet to 0.55 millirem/hour at 39,000 feet. The mean radiation level therefore depends strongly on the choice of the representative mean flight altitude. Since a sizeable part of the total RPM is spent on climbs and descents, the mean radiation level can be assumed to be closer to the value at 31,000 than at 39,000 feet. We therefore have chosen the value of 0.4 millirem/hour as mean radiation level during flight. Multiplying it by the mean duration of 2.5 hours per trip, we obtain the value of 1 millirem as the mean dose equivalent per trip.

With the dose per trip set exactly at 1 millirem, the number of trips per year designates directly the passenger dose in millirems per year, as indicated by the double notation of the first column in Table II. By the same token, the values of column 5 represent passenger trips as well as radiation loads in man-millirems. Converting man-millirems to man-rems, we see at the bottom of column 5 that the total radiation

load per year from air travel is 99,878 man-rems. Divided by 26,224,000 passengers for a 12-month period, this load corresponds to a mean passenger dose of 3.8 millirems/year. Divided by the total population of 210,000,000, it furnishes a population dose of 0.48 millirem per capita per year.

Table III

Exposure Distribution for Radiation Workers

Dose Interval (rem/year)	Number of Workers	Number of Workers (per cent)	Radiation Load (man-rem/year)
0-0.1	328,982	71.52	16,449
0.1-0.2	38,961	8.47	5,844
0.2-0.5	44,251	9.62	15,488
0.5-1.0	25,069	5.45	18,802
1-2	12,328	2.68	18,492
2-3	5,750	1.25	14,375
3-4	2,438	0.53	8,533
4-5	920	0.20	4,140
5-6	460	0.10	2,530
6-7	276	0.06	1,794
7-8	138	0.03	1,035
8-9	138	0.03	1,173
9-10	184	0.04	1,748
10-11	92	0.02	966
11-12	46	0.01	529
12+	46	0.01	575
Total	460,079		112,473

Turning to the exposure distribution for radiation workers under the control of the AEC, we show in Table III pertinent data listing average yearly exposures for 1968 and 1969 (C. G. Welty, Jr., personal communication). It is interesting to see that despite the strong disparity of the input data for the exposure distribution of air passengers in Table II, as compared to the corresponding distribution of radiation workers in Table III, the grand totals of yearly radiation loads in man-rems are very nearly equal. While the population of 26 million traveling by air is very much larger than the population of 460,000 radiation workers, the respective radiation doses are by coincidence inversely different in such a way that the grand totals very nearly

balance. A total radiation load of 99,878 man-rems per year from air travel compares to a load of 112,473 man-rems for radiation workers. Dividing the latter load by the number of workers shown in Table III as 460,079, we obtain a mean dose of 244 millirems per year for radiation workers. Dividing it by the total population of the United States (210,000,000), we obtain a population dose of 0.54 millirem/year per capita.

The fact that the population doses for air travelers and for radiation workers are very nearly equal is all the more remarkable because the two distributions do not differ greatly merely in absolute values of class entries but also differ with regard to their overall configurations. The latter difference is best demonstrated by normalizing the initial sections of both distributions, plotting exposure levels in multiples of the lowest class. The histogram in Figure 2 shows the normalized initial sections. It is seen that the distribution for radiation workers drops much more steeply in the initial classes than the distribution for air travelers. At the upper end, not shown in Figure 2, the distributions differ in an opposite manner. Whereas the maximum yearly exposure for air travel will always stay well below the theoretical value of 4800 millirems for somebody remaining continuously at a 39,000-foot altitude, no upper dose limit exists for radiation workers. Rare instances of emergencies and accidents entail, for a very

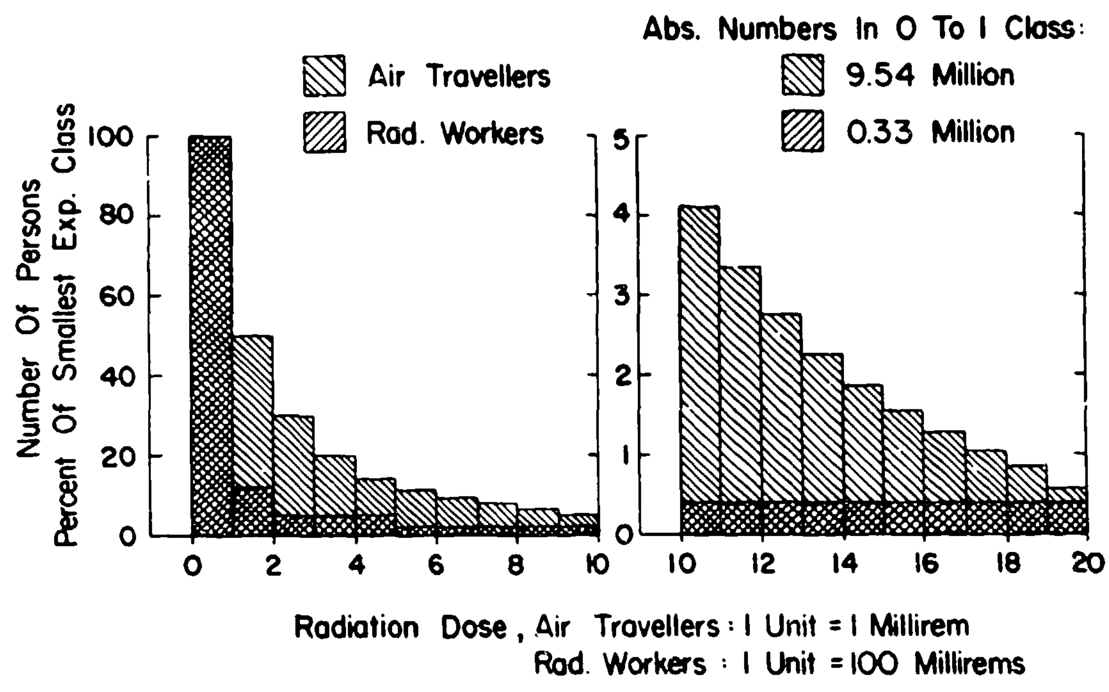

Figure 2

Initial Sections of Normalized Exposure
Distributions of Air Travelers and Radiation Workers

small number of radiation workers, exceptionally high exposures. This ever-present danger contrasts sharply with the situation in air travel where doses from environmental ionizing radiation always remain trivial. Not only is the maximum possible exposure for the air traveler safe, it is also predictable and entirely dependent on the decision of the individual passenger as to how many hours per year he would want to spend traveling by air.

After the basically different nature of the radiation exposure of the public in air travel as compared to the corresponding exposure of radiation workers has been shown, spelling out the risk factor involved in air travel seems farfetched. However, with modern technology creating a number of man-made additions to the natural background of ionizing radiation, even small contributions should be evaluated.

It should be obvious that radiation exposure in air travel ranging from 1 to about 25 millirems per year implies a very small risk. For such low yearly doses, only subtle long-term effects are involved. The two types of chronic radiation injuries, which usually are examined if large populations are involved, are radiation-induced leukemia and life shortening. They differ basically with regard to their statistical manifestation in the exposed population. Leukemia is strictly an all-or-nothing type effect, manifesting itself statistically in the number of stricken individuals. Quite differently, shortening of life span affects all exposed individuals although with a certain statistical spread in the quantity of effect.

Induction of leukemia by ionizing radiation has been investigated extensively; present estimates range from 1 to 2×10^{-6}/rem/year. That means that if 1,000,000 persons receive a dose of 1 rem each, there will occur among them one or two cases of leukemia within 1 year following the exposure, which would not have occurred without the exposure. The natural incidence of leukemia in the population of the United States is 70 to 120 cases per 1,000,000 persons per year. It is seen at once that even for the highest exposure during air travel of 25 millirems per year, the increase in the natural rate is only 0.05 per cent. Data on life shortening by ionizing radiation are less reliable than those on induction of leukemia. Extrapolating detailed information on mice to man, radiobiologists have estimated the life-shortening effect at 10 days per rem for acute and 2.5 days per rem for chronic exposures. Even if the higher first value is selected, 25 millirems/year would correspond to a life shortening of only 6 hours per year. It must further be pointed out that the assessments of risk increases for both endpoints, leukemia and life shortening, are based on linear regression. That means that experimental or empirical data obtained for medium- and high-exposure levels have been extrapolated to the very small doses involved, assuming a linear/dose effect relationship down to zero dose. If finite safe threshold doses should exist below which the effect is zero, the risk increases, found to be marginal already for the linear model, would further drop to altogether insignificant levels.

In conclusion, it should be emphasized again that evaluation of the trivial risk from environmental radiation in air travel was not the purpose of this tudy. The salient point was explicit quantitative demonstration of the basically different nature of the sources of two apparently equal man-made additions to the population dose, one, travel by air, intrinsically harmless, the other, working near nuclear installations, potentially hazardous and requiring continuous monitoring of exposure.

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